A NEW CLASSIFICATION AND A TWO-PARAMETER UNIFICATION OF BL LACERTAE OBJECTS

MARKOS GEORGANOPOULOS AND ALAN P. MARSCHER

Department of Astronomy, Boston University
725 Commonwealth Avenue, Boston, MA 02215, USA

Abstract. A new continuous classification system for BL Lacertae (BL Lac) objects is proposed. The peak frequency ν_p of the synchrotron component in the νL_ν spectrum is used as a classifying parameter. The application of the accelerating inner jet model to complete BL Lac samples suggests that the range of the observed properties may be explained by adopting a description based on two parameters: the jet angle to the line of sight Θ, and the relativistic electron kinetic luminosity Λ_e.

1. Classification of BL Lacertae objects

BL Lac objects are discovered mostly through X-ray or radio surveys. The existing complete samples therefore are either X-ray (Morris et al. 1991) or radio flux-limited samples (Stickel et al. 1991) and BL Lac objects are classified as XBL (X-ray selected) or RBL (radio selected) depending on the method of discovery. The νL_ν spectra of RBLs peak somewhere in the far-infrared and have a higher peak luminosity than the XBLs that usually peak in the UV - soft X-ray range (Sambruna, Maraschi & Urry 1996, hereafter SMU96). According to a recently proposed scheme (Padovani & Giommi 1995), BL Lac objects are classified as high peak frequency BL Lac objects (HBL) or low peak frequency BL Lac objects (LBL), depending on the value of the X-ray to radio-flux ratio. Most of the HBLs are XBLs and most of the LBLs are RBLs. Although this classification scheme reflects more closely the observed properties of the BL Lac objects, it inherits the dichotomization that was imposed by the two different discovery methods. If the two methods of discovery force us to observe the two extremes of a continuous distribution, thereby introducing a selection induced bimodality, the question that arises is whether there is an observed quantity that varies
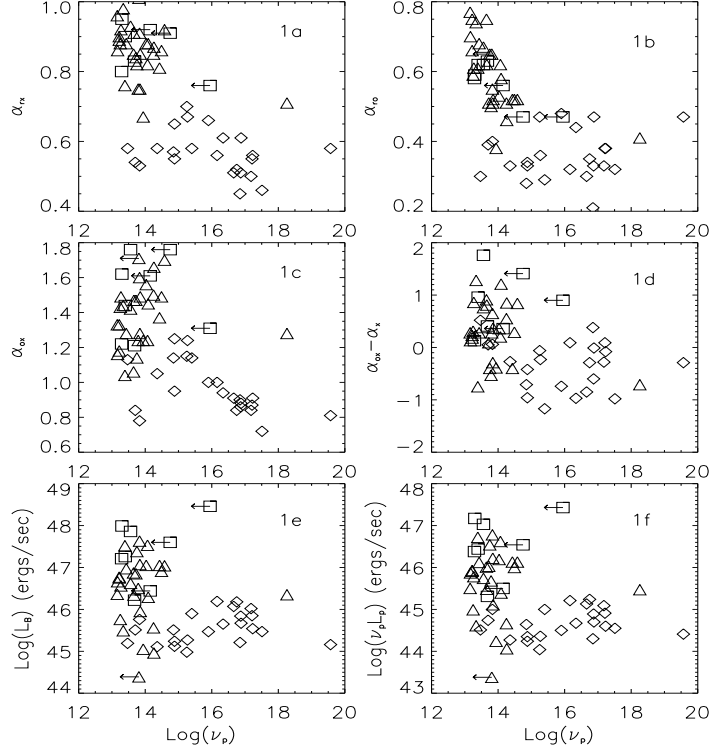
Figure 1.   The (a) radio to X-ray (α_{rx}), (b) radio to optical (α_{ro}), (c) optical to X-ray (α_{ox}) broadband spectral indices, (d) the X-ray concavity index $\alpha_{ox} - \alpha_x$, (e) the bolometric synchrotron luminosity L_B, and (f) the peak luminosity $\nu_p L_p$ as a function of the peak frequency ν_p for the XBL (diamonds), RBL (triangles), and FSRQ (squares) samples of SMU96. Arrows indicate objects with only an estimated upper limit to the peak frequency ν_p.

in a continuous fashion, has a well defined physical significance, and can be used as a classifying parameter.

2. A new classification system

Recently SMU96 examined the multifrequency spectral properties of three complete samples of blazars, the *Einstein* Extended Medium Sensitivity Survey sample of XBLs (Morris et al. 1991), the 1 Jy sample of RBLs (Stickel et al. 1991), and a small complete sample of FSRQ from the S5 survey (Brunner et al. 1994). If we consider the BL Lac samples collectively (fig. 1) we notice that in all six diagrams there is an upper envelope separating the populated area from a well defined zone of avoidance. For a given peak frequency ν_p there is a permitted range of luminosities and spectral indices. As ν_p increases the maximum observed luminosity decreases, the

steepest observed spectral index flattens, and the maximum observed concavity index $\alpha_{ox} - \alpha_x$ decreases. The flattest spectral indices and the most negative concavity indices do not seem to be very sensitive functions of ν_p.

We propose a continuous classification system for BL Lac objects, based on the peak frequency ν_p of the νL_ν synchrotron luminosity distribution. A BL Lac object is classified according to its peak frequency ν_p. For example, a BL Lac object peaking at $log(\nu_p) \cong 14$ will be classified as a *BL14* object.

The peak frequency of a BL Lacertae object is a very important parameter from a physical point of view. Energetically, it is the most important frequency for the observed synchrotron radiation. It is closely related to the peak of the inverse Compton emission in both the Synchrotron-self Compton (SSC) (Bloom & Marscher 1996) and the external Compton (EC) models (Sikora, Begelman, & Rees 1994). It is linked to the energetics and geometry of the synchrotron source and to the angle formed between the observer and the plasma bulk velocity, if the source is moving relativistically (Georganopoulos & Marscher 1996). As SMU96 pointed out the accurate determination of ν_p requires contemporaneous flux measurements in different wavelength regimes. The contribution of new telescopes such as ISO towards this goal can be particularly important.

3. The $\Theta - \Lambda_e$ scheme

Orientation and physical differences have been evoked to explain the range of the observed properties of BL Lac objects (SMU96 ; Georganopoulos & Marscher 1996). Under the proposed taxonomical scheme the problem of the XBL-RBL differences can be restated as follows: *What is changing as we continuously shift from a BL13 to a BL17 object?*

Recently, Georganopoulos & Marscher (1996) used the accelerating inner jet model to argue that, although the mean properties of XBL and RBL samples can be explained under the orientation-determined scenario, the sources seem to be additionally characterized by a range of physical parameters. It seems therefore necessary to invoke the scaling of an appropriate physical quantity that would preserve the observed self-similarity of the relativistic jets from the galactic to the extragalactic scale. An observed physical parameter that is known to vary over several decades in relativistic jets and over almost three decades in BL Lac objects is the synchrotron peak luminosity L_p. A plausible way to explain this range of L_p is to associate it with an intrinsic range of the relativistic electron kinetic luminosity Λ_e. In a scale invariant description of the jet, the luminosity relates to the jet radius according to the relation $r \propto \Lambda_e^{1/2}$ (Georganopoulos & Marscher 1997).

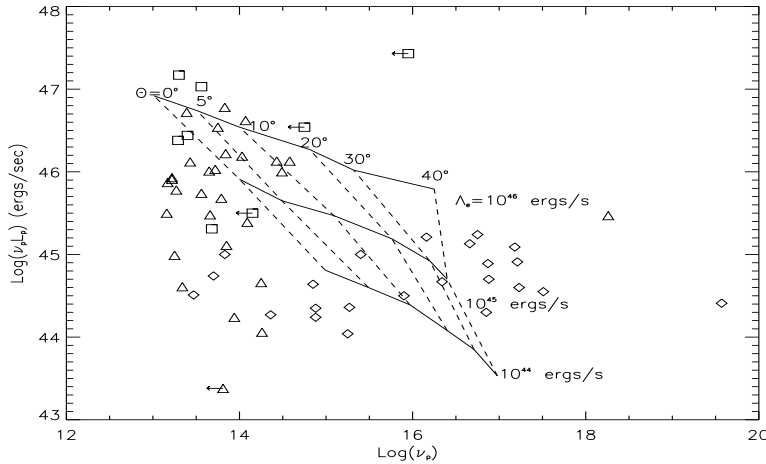Preliminary results (fig. 2) show that a combination of a range of elec-

Figure 2.   Peak luminosity $\nu_p L_p$ versus peak frequency ν_p. The data points are as in fig. 1. The solid lines correspond to the migration of the model prediction as the angle Θ changes from 0° to 40° for a set of electron kinetic luminosity Λ_e. The dashed lines are lines of constant angle Θ.

tron kinetic luminosities Λ_e and jet orientation angles Θ covers a major part of the observed $\nu_p - \mathrm{L}_p\nu_p$ space. It is very encouraging that this can be achieved only through variation of aspect and jet power. We are continuing our work by comparing the predicted and observed properties of BL Lac objects as well as by incorporating the flat spectrum radio quasars in the above scheme.

References

Bloom, S.D., & Marscher, A.P. (1996) An Analysis of the Synchrotron Self-Compton Model for the Multi–Wave Band Spectra of Blazars, *ApJ*, **Vol. 461**, pp. 657-663

Brunner, H., Lamer, G., Worrall, D.M., & Staubert, R. (1994) X-ray spectra of a complete sample of extragalactic core-dominated radio sources, *A&A*, **Vol. 287**, pp. 436-452

Georganopoulos M., & Marscher, A.P. (1996) The accelerating jet model: Steady state and variability properties of Blazars, in Blazar Continuum Variability, ASP Conference Series, **Vol. 110**, eds H.R. Miller, J.R. Webb, & J.C. Noble, pp. 262-267

Georganopoulos M., & Marscher, A.P. (1997), in preparation

Morris, S.L., Stocke, J.T., Gioia, I.M., Schild, R.E., Wolter, A., Maccacaro, T., & Della Cesa, R. (1991), The luminosity function and cosmological evolution of X-ray selected BL Lacertae objects, *ApJ*, **Vol. 380**, pp. 49-66

Padovani, P. & Giommi, P. (1995) The connection between X-ray and radio-selected BL Lacertae objects, *ApJ*, **Vol. 444**, pp. 567-581

Sambruna, R.M., Maraschi, L., & Urry, C.M. (1996) On the spectral energy distribution of Blazars, *ApJ*, **Vol. 463**, pp. 444-465 (SMU96)

Sikora, M., Begelman, M.C., Rees, M.J. (1994), Comptonization of diffuse ambient radiation by a relativistic jet: the source of gamma rays from blazars? *ApJ*, **Vol. 421**, pp. 153-162

Stickel, M., Padovani, P., Urry, C.M., Fried, J. W., & Kühr, H. (1991), The complete sample of 1 Jansky BL Lacertae objects. I. Summary properties, *ApJ*, **Vol. 374**, pp.

431-439